

Design and Analysis of Aircraft Wing Rib with Different Configuration for A380 model

A J Sriganapathy¹, K Akash², M Susiendhar Baabu³, S Arumugam⁴, M Vishnu⁵

¹*Assistant Professor- Department of Aeronautical Engineering, Mahendra Institute of Engineering and Technology, Tiruchengode, Namakkal, Tamilnadu, India*

^{2,3,4,5}*UG student of Aeronautical Engineering, Mahendra Institute of Engineering and Technology, Tiruchengode, Namakkal, Tamilnadu, India*

ABSTRACT

The wing rib of an aircraft is a very critical part. It provides airfoil contour to the wing. Its principal role in wing structure is that to transfer load from skin to stringers or other parts of wing. Cut-outs in aircraft structural components such as wing spars and ribs are commonly encountered in practice. Cut-outs are often necessary for lightening holes, passages for wire bundles, hydraulic and fuel pipes, control linkages, accessibility for final assembly and maintenance inspections. The shape of the cutout is a important parameter where depends on the cutout shape the structural parameters may get varied. The main objective in here is to study about the influence of cutout in rib section with different cutout shapes. The Airbus A380 model is considered and the rib section for the model is modeled using Solidworks modeling package and the model is analyzed for different cutout shapes. The model has the cutout shapes such as circle, ellipse and rectangle, where the circular hole is a most practiced method in recent models. The numerical analysis is carried out in ANSYS static structural analysis to find the structural parameters such as stress, strain, deformation and weight.

1.INTRODUCTION

Ribs are the structural crosspieces that combine with spars and stringers to make up the framework of the wing. They usually extend from the wing leading edge to the rear spar or to the trailing edge of the wing. The ribs give the wing its cambered shape and transmit the load from the skin and stringers to the spars. Similar ribs are also used in ailerons, elevators, rudders, and stabilizers. Wing ribs are usually manufactured from either wood or metal. Aircraft with wood wing spars may have wood or metal ribs while most aircraft with metal spars have metal ribs. Wood ribs are usually manufactured from spruce. The three most common types of wooden ribs are the plywood web, the lightened plywood web, and the truss types. Of these three, the truss type is the most efficient because it is strong and lightweight, but it is also the most complex to construct. It shows wood truss web ribs and a lightened plywood web rib. Wood ribs have a rib cap or cap strip fastened around the entire perimeter of the rib. It is usually made of the same material as the rib itself. The rib cap stiffens and strengthens the rib and provides an attaching surface for the wing covering., the cross-section of a wing rib with a truss-type web is illustrated. The dark rectangular sections are the front and rear wing spars. Note that to reinforce the truss, gussets are used. a truss web rib is shown with a continuous gusset. It provides greater support throughout the entire rib with very little additional weight. A continuous gusset stiffens the cap strip in the plane of the rib. This aids in preventing buckling and helps to obtain better rib/skin joints where nail-gluing is used. Such a rib can resist the driving force of nails better than the other types. Continuous gussets are also more easily handled than the many small separate gussets otherwise required. shows a rib with a lighten plywood web. It also contains gussets to support the web/cap strip interface. The cap strip is usually laminated to the web, especially at the leading edge. A wing rib may also be referred to as a plain rib or a main rib. Wing ribs with specialized locations or functions are given names that reflect their uniqueness. For example, ribs that are located entirely forward of the front spar that are used to shape and strengthen the wing leading edge are called nose ribs or false ribs. False ribs are ribs that do not span the entire wing chord, which is the distance from the leading edge to the trailing edge of the wing. Wing butt ribs may be found at the inboard edge of the wing where the wing attaches to the fuselage. Depending on its location and

method of attachment, a butt rib may also be called a bulkhead rib or a compression rib if it is designed to receive compression loads that tend to force the wing spars together. Since the ribs are laterally weak, they are strengthened in some wings by tapes that are woven above and below rib sections to prevent sidewise bending of the ribs. Drag and anti-drag wires may also be found in a wing. they are shown crisscrossed between the spars to form a truss to resist forces acting on the wing in the direction of the wing chord. These tension wires are also referred to as tie rods. The wire designed to resist the backward forces is called a drag wire; the anti-drag wire resists the forward forces in the chord direction. Figure 14 illustrates the structural components of a basic wood wing

2. LITERATURE SURVEY

Rahul Sharma and Garima Garg, have investigated stress and displacement of wing rib with and without cut-outs of 1mm thickness within the application of 0.01Mpa air pressure. CATIA V5 and MSC NASTRAN-PATRAN are the tools utilized in this design and analysis. The work was focused on stress analysis and displacement of both the categories of wing ribs (with and without cut-outs). It had been found that the maximum deformation for wing rib without cut-out was less than the maximum deformation for wing rib with cut-outs. The advantage of wing rib with cut-out is that it is cheaper and lighter in weight than wing rib without cut-outs. **S Bairavi, Mr. Suresh Balaji**, in their paper they have come to the conclusion that when cut outs are present in aircraft wing ribs it creates stress concentration which eventually reduces the mechanical strength of the structure and in extreme cases may cause failure. In this paper the induced stress for ribs with circular, elliptical and rectangular cut outs have been found with the help of finite element software package ANSYS 14. **Mohamed Amine Bennaceur, Yuan-ming Xu and HemzaLayachi**, in their paper they have used the constrained natural element method to optimize the cutout in the wing ribs of a light aircraft by adopting three different configurations and showed that changing the configuration of cut out will increase the strength of wing rib. In the configuration with trapezoid holes, it leads to optimal stability performance to sustain shear load additionally. **Bindu H C, Muhammad Muhsin Ali H**, in their paper they have demonstrated to increase the critical buckling strength and reduced the weight of rib. Buckling analysis and linear static are performed on the idealized configuration using FEM packages. It was found that introducing circular holes in the wing rib enhances the buckling strength of it. As the number of holes increases the buckling strength of the wing rib also increases. Insertion of holes in the rib was found to be effective with the weight reduction compared to initial geometry. The maximum stress occurs around the holes and this factor must be considered. **Kannan. T, Mr. Veeranjanyulu**, this research paper includes design and analysis of aircraft wing rib using different composite materials. Based on the classical approach, the optimum design parameters for an aircraft's wing rib have been suitably selected. Here they have used CAD software to design the three-dimensional aircraft wing rib. Analysis is done for structural wing rib for different loads and fibre orientation. Stress tensor and critical displacement were calculated from finite element tool. They have compared the results for different fibre orientation. **J.A. Newlin and Geo.W.Trayer**, they have conducted tests for many designs of wing ribs and these are compared with different types of sizes. Ribs of any size or proportion was discovered, once they were designed to induce a well-balanced construction and that they were manufactured carefully. They observed that reduction in weight of aircraft wing ribs is even more in efficient designs by greater proportional reduction in strength. **GugulothKavya, B C Raghukumar Reddy**, have demonstrated aircraft wing design in 3D modelling software and it is modified by adding ribs and spars. By applying three materials such as S Glass, Kevlar 49 and Boron Fiber, static structural analysis is done. Buckling analysis, modal analysis and FEM analysis are done on aircraft wing and aircraft wing with ribs and spars. They describe, that addition of wing ribs and spars increases the strength of wing and material S Glass gives better results.

3. MODELLING OF RIB WITH CUT-OUTS

3.1 Rib Design

The Rib was modelled using Solidworks software with standard dimensions. Solidworks is a solid modelling computer-aided design (CAD) and computer-aided engineering (CAE) software program that runs on Microsoft Windows. The Solidworks was produced by the Dassault Systems. Building a model in Solidworks usually starts with a 2D sketch (although 3D sketches are available for power users). The sketch consists of geometry such as points, lines, arcs, conics (except the hyperbola), and splines

In an assembly, the analogues to sketch relations are mates. Just as sketch relations define conditions such as tangency, parallelism, and concentricity with respect to sketch geometry, assembly mates define equivalent relations with respect to the individual parts or components, allowing the easy construction of assemblies. Views are automatically generated from the solid model, and notes, dimensions and tolerances can then be easily added to the drawing as needed. The drawing module includes most paper sizes and standards (ANSI, ISO, DIN, GOST, JIS, BSI and SAC).

3.2 Modelling of Rib let

The modelling of Rib starts with selection of an Airfoil profile. NASA SC(2) 0610 Airfoil was chose for this design. That airfoil was imported into Solidworks software. The chord length of an airfoil was set to 10.59 m. From the design calculations, the riblet front should start at 1.5885m from the leading edge of an airfoil, and chord of riblet should be 5.295m. The total chord of rib let was divided into 3 sections at equal distances. The cross section of rib lets was in I-section at all 3 sections. The width of I-section was maintained 0.3m constant at all sections, were, height varies with respect to airfoil shape.

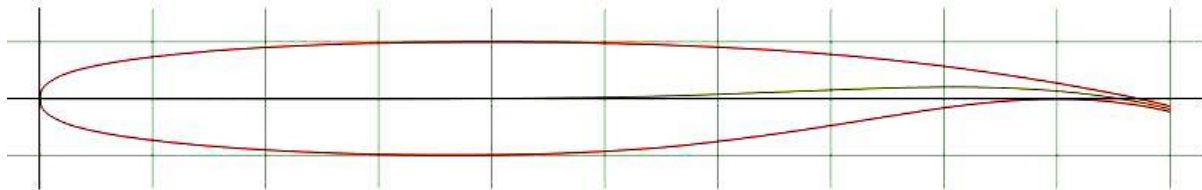


Fig 3.1(a)

The I-Section at plane - 1 was created using Sketch command in Solidworks. Again at section -2, I – section was created with Different height with respect to Airfoil shape. Also at section – 3, I - section was created. So we created 3 sketches in each section planes.

Loft command in Solidworks was used to connect sketches at multiple sectional planes to form required 3D models. Using a Loft command in Solidworks, we connect all 3 sketches to form the riblet in airfoil shape.

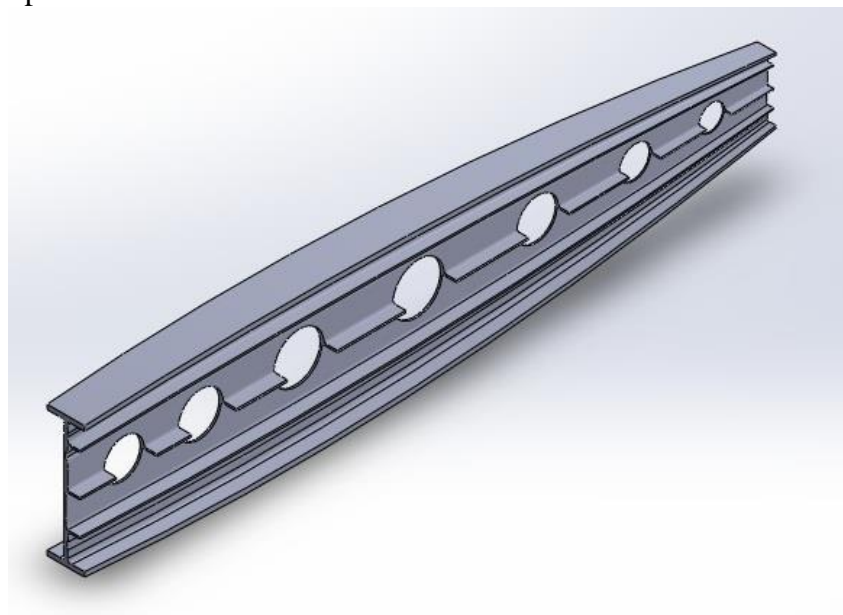


Fig 3.1 (b) Circular Cut-out

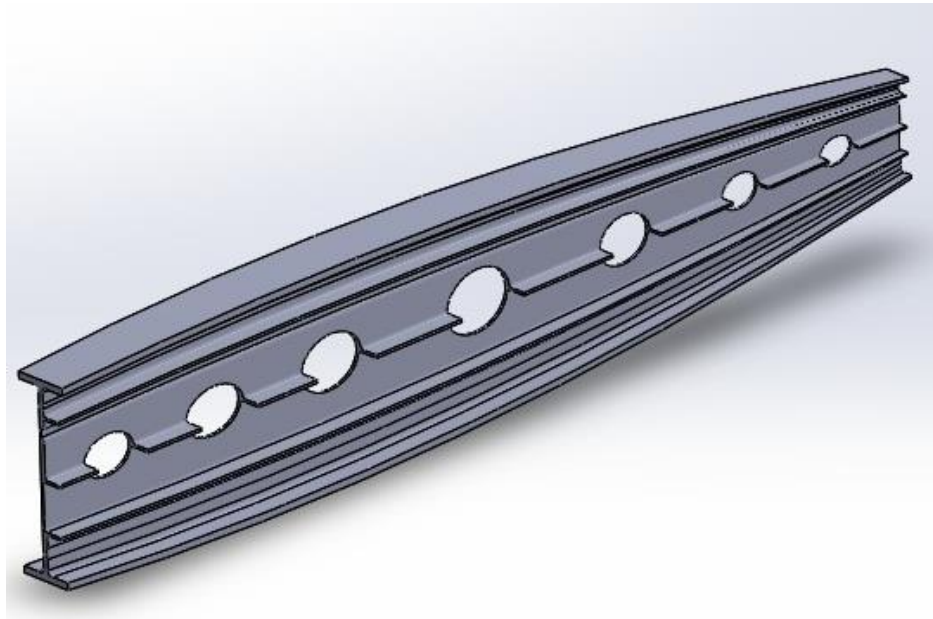


Fig 3.1 (c) Elliptical Cut-out

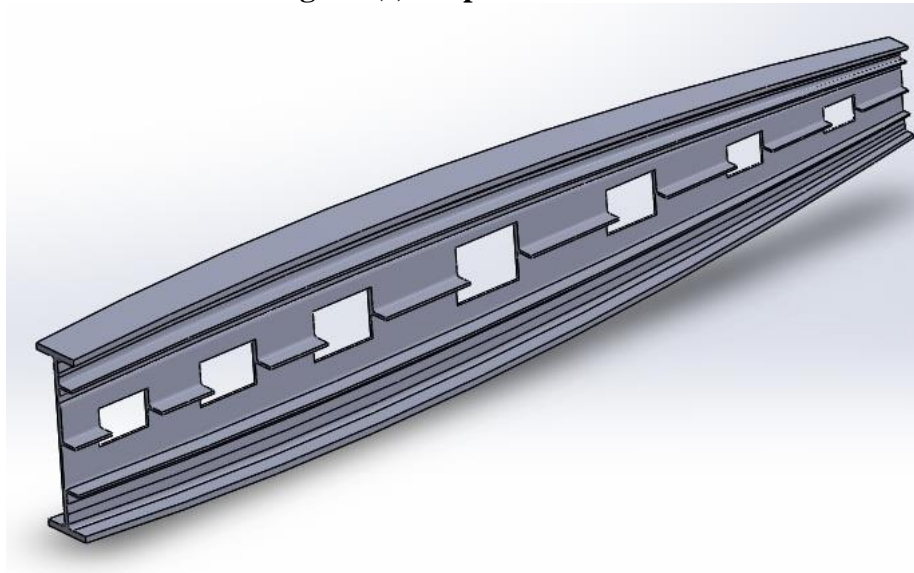


Fig. 3.1 (d) Rectangular Cut-out

After creating Riblets, multiple holes should be formed in axial direction. The holes are in three different shapes. They are circle, ellipse, and rectangle. The dimensions of the cut out and its locations are as illustrated in the below figure.

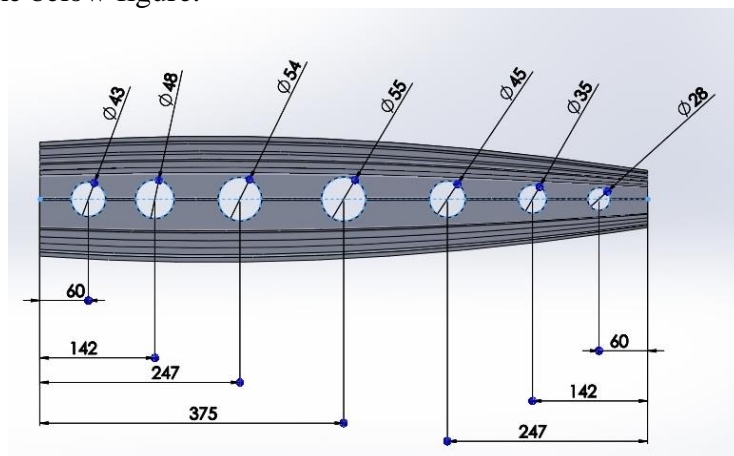


Fig 3.1 (e) circular cut-out

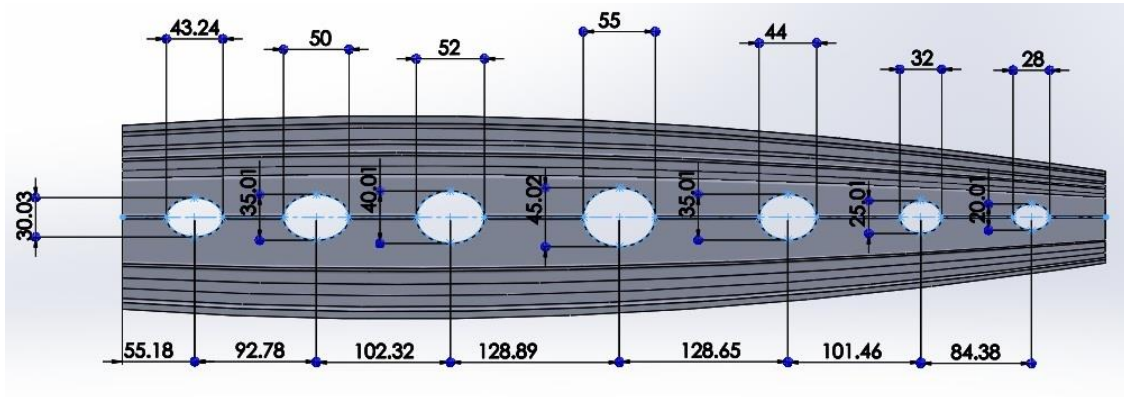


Fig 3.1 (f) Elliptical cut-out

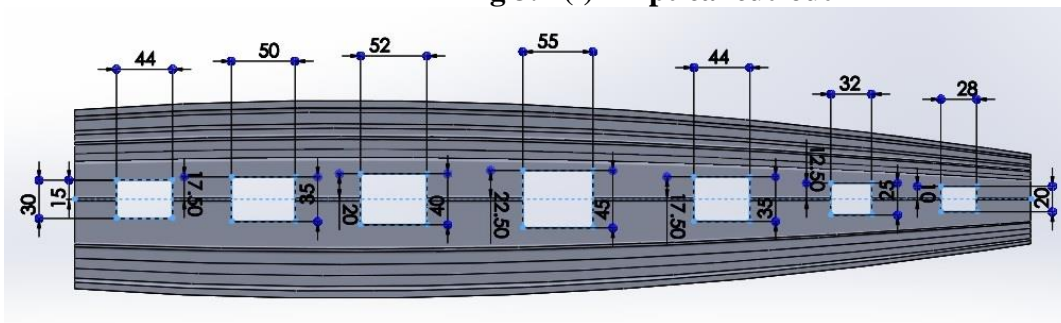


Fig 3.1 (g) Rectangular cut-out

4. NUMERICAL ANALYSIS

4.1 FEA

Finite Element Analysis (FEA) is one of the branches of solid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve analysis of structures or objects. Computers are used to simulate the interaction of forces over the surfaces defined by boundary conditions. Even with high-speed supercomputers only approximate solutions can be achieved in many cases. The finite element method (FEM) is a widely used method for numerically solving differential equations arising in engineering and mathematical modeling. Typical problem areas of interest include the traditional fields of structural analysis, heat transfer, fluid flow, mass transport, and electromagnetic potential. The FEM is a general numerical method for solving partial differential equations in two or three space variables (i.e., some boundary value problems). To solve a problem, the FEM subdivides a large system into smaller, simpler parts that are called finite elements. This is achieved by a particular space discretization in the space dimensions, which is implemented by the construction of a mesh of the object: the numerical domain for the solution, which has a finite number of points. The finite element method formulation of a boundary value problem finally results in a system of algebraic equations. The method approximates the unknown function over the domain. The simple equations that model these finite elements are then assembled into a larger system of equations that models the entire problem. The FEM then uses variational methods from the calculus of variations to approximate a solution by minimizing an associated error function.

4.2 OUTLINE OF FINITE ELEMENT ANALYSIS PROCESS

Finite Element Analysis codes are structured around the numerical algorithms that can tackle all kinds of structural problems. All the FEA codes available in the market have three basic elements which divide the complete analysis of the numerical experiment to be performed on the specific domain or geometry.

The three basic elements are

- i.Pre-processor
- ii.Solver and
- iii.Post-Processor

4.3. MATERIAL SELECTION

Aluminium is the one of the major material used in the aircraft. The aluminium has less weight and better performance than other materials. It has a different grade based on the compositions used. Most of the aircraft structural components are made of Aluminium 7075-T6 or Aluminium 7010 or Aluminium 2024 material only. Most preferred material for the rib section would be the Aluminium 7075-T6 only, which is due to its less weight and higher performance.

Table: 4.1 Material property

| Property | 7075-76 Aluminium alloy |
|----------------------------------|-------------------------|
| Density | 2.81 g/cm ³ |
| Young's Modulus | 71.7 GPa |
| Coefficient of Thermal Expansion | 23.6 μC ⁻¹ |
| Reference Temperature | 20°C |
| Poisson's Ratio | 0.33 |
| Tensile Yield Strength | 503 MPa |
| Tensile Ultimate Strength | 572 MPa |

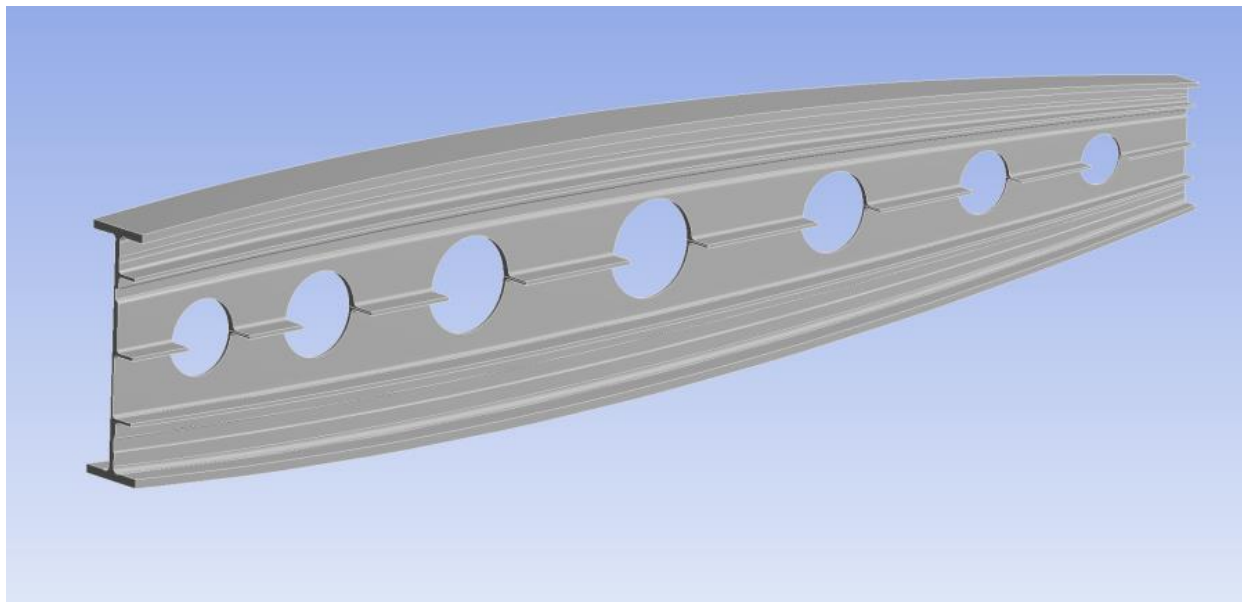


Figure 4.1 Rib sections

4.4. GEOMETRY CREATION

In this process, geometry for the rib section is created. The rib section modeled in SOLIDWORKS earlier which is a 3D model. The model has to be imported as an IGS file format to get a proper structure. The imported model is as shown in figure.5.1.

4.5. MESHING

Different meshing characteristics were used for the domain. Although the methods were different, the same mixed configuration of triangular and quad core cells were used for the domain. The triangular shape surface mesh was used due to its proximity to changing curves and bends. These elements easily adjust to the complex bodies used in automobile and aerospace. In the simulations, the piston component surfaces were discretized with triangular mesh elements. Cells of mixed cell type were used in the meshing the piston model. The mesh model of the rib section is shown in below figure.5.2.

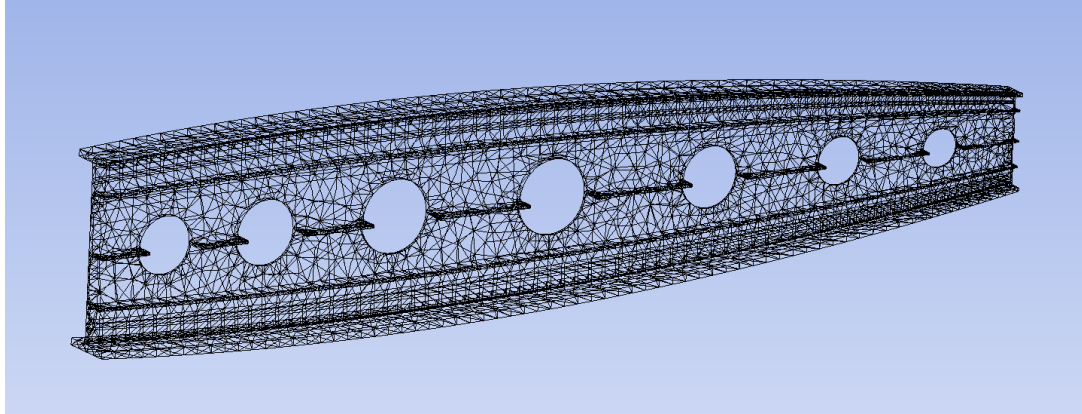


Figure.4.2 Mesh model of Circle cutout

The mesh parameters defined is as given below:

| | |
|--------------------|-------------|
| Relevance Center | : Fine |
| Span Angle Center | : Fine |
| Minimum Size | : 0.7894 mm |
| Growth Rate | : 1.850 |
| Number of Nodes | : 113153 |
| Number of Elements | : 64484 |

4.6. BOUNDARY CONDITIONS

The problem is a structural analysis problem. The boundary condition for the problem is with a pressure force at the bottom and a force applied over the top face. The pressure force is calculated using the lift force and the force at the top is calculated using the summation of structural load, fuel load and engine load. The calculation for the forces is as given below. The boundary conditions for the rib section are shown in figure.5.3.

Load = Fuel weight + Structural weight + Engine Weight

Gross Weight (W_G) = 575000 Kg

Fuel Weight = 0.2 W_G = 0.2 * 575000 = 115000

Structural weight = 0.14 W_G = 0.14 * 575000 = 80500

Engine weight = 0.06 W_G = 0.06 * 575000 = 34500

Load = 230000 Kg

Force = 230000 * 9.81 = 2256300 N

Pressure Force:

$$L = 0.5 \rho V^2 S C_L$$

$$= 0.5 * 1.225 * 293.7^2 * S * 1.48$$

Pressure = L / A

$$= (0.5 * 1.225 * 293.7^2 * S * 1.48) / S$$

$$= 0.767 \text{ MPa}$$

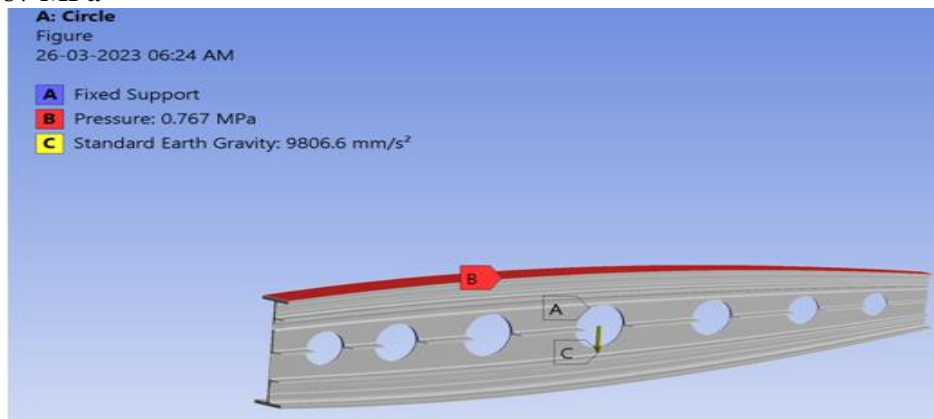


Figure.4.3 Boundary condition

4.7. NUMERICAL RESULTS

The structural behavior of the rib has been studied for the above mentioned boundary conditions. The results obtained by these are shown in below. The table.5.2 shows the structural behavior of the rib section.

Case: 1 – Circular cutouts

Case: 2 – Ellipse cutouts

Case: 3 – Rectangular cutouts

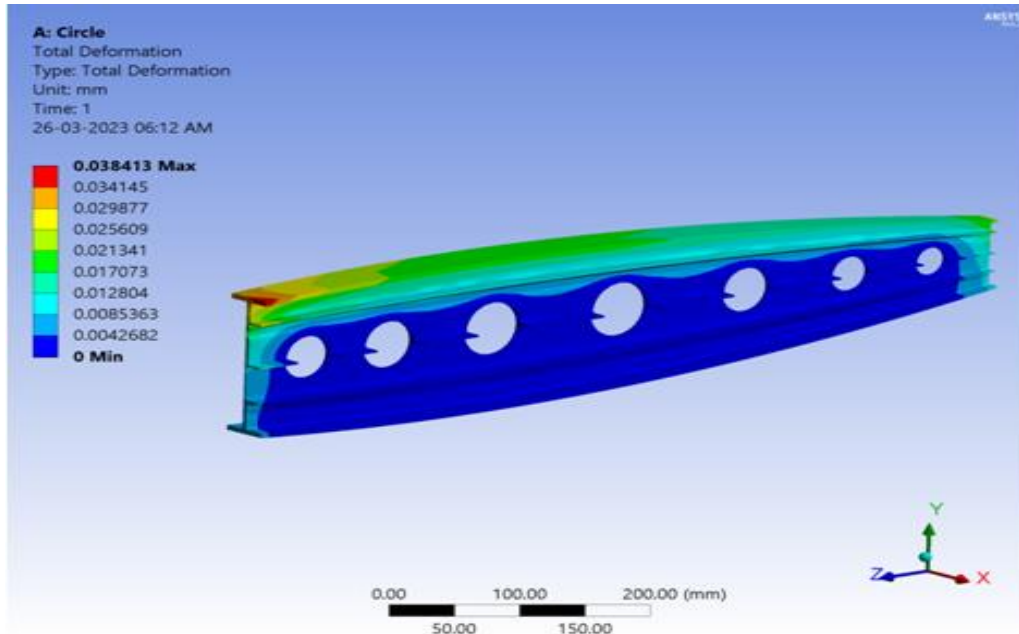


Figure.4.4 Deformation for Circular Cut-out

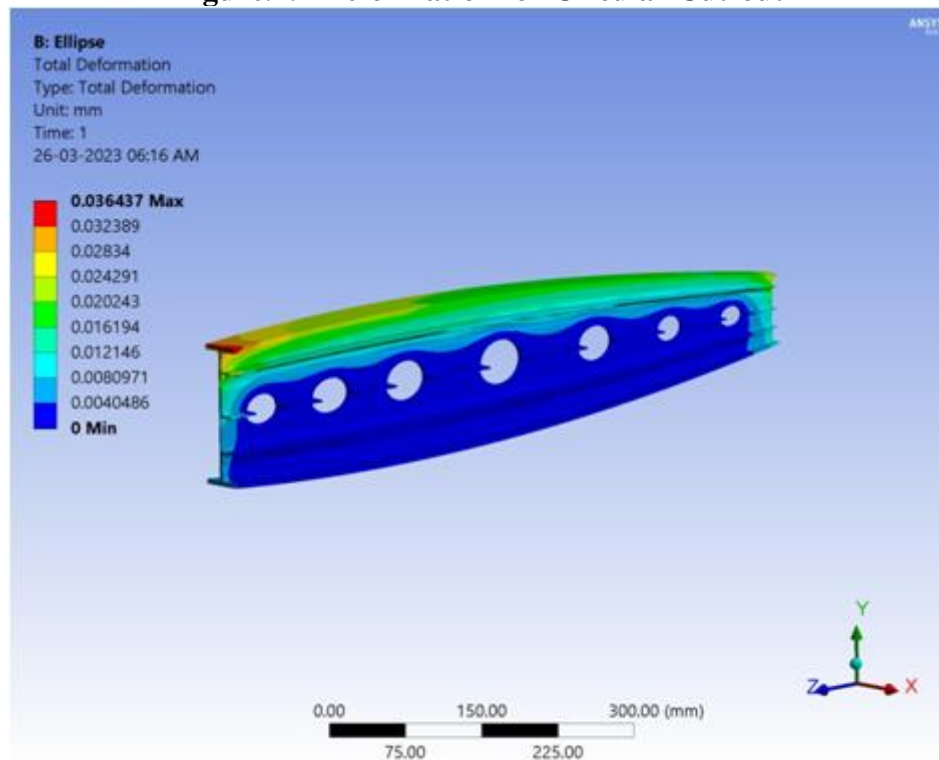


Figure.4.5 Deformation for Elliptical Cut-out

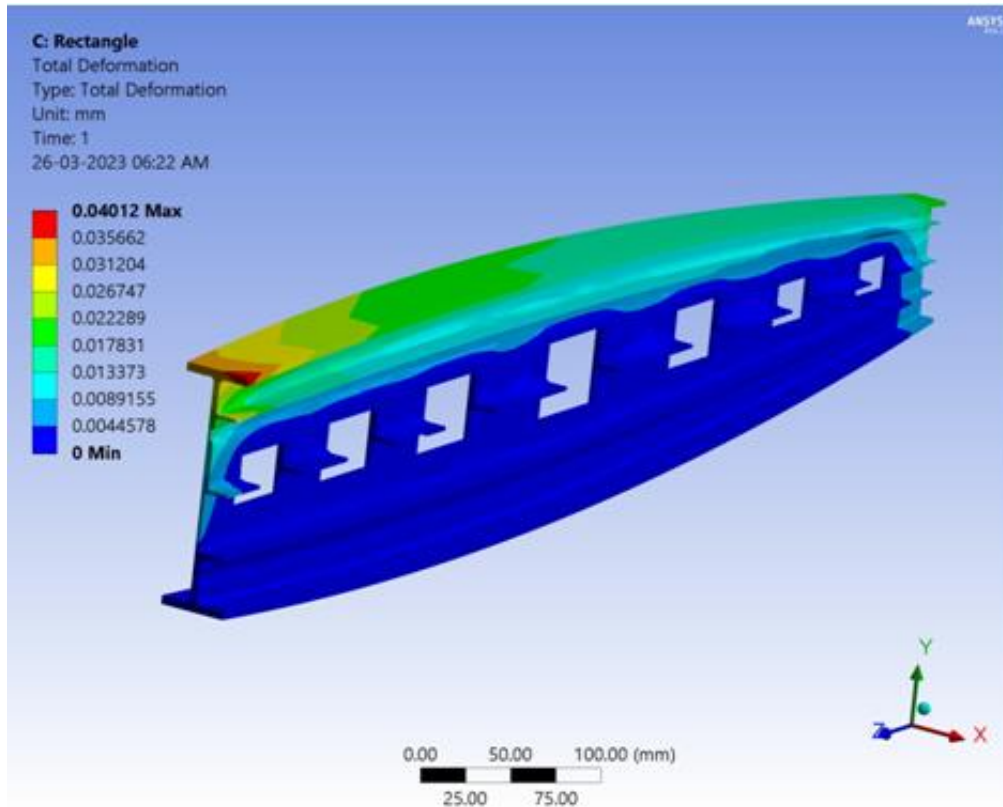


Figure.4.6 Deformation for Rectangular Cut-out

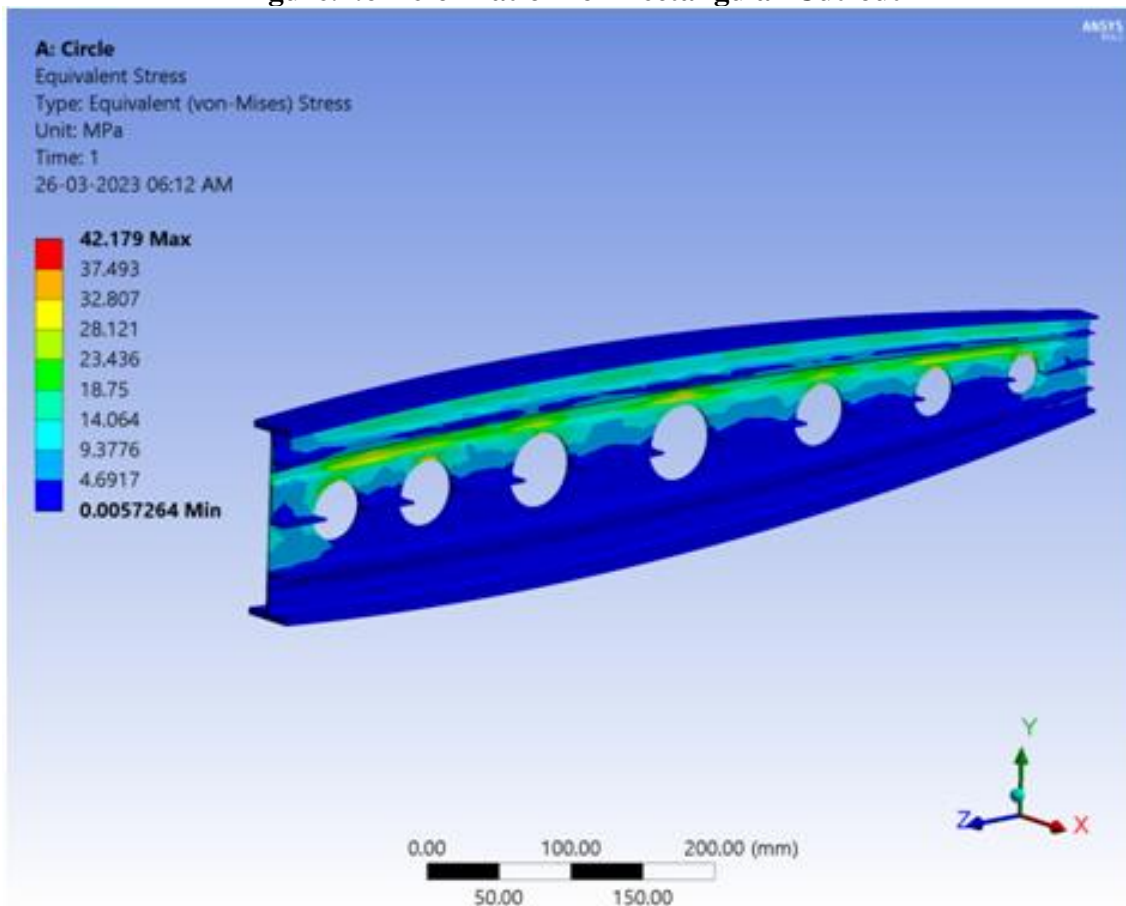


Figure.4.7 Stress for Circular Cut-out

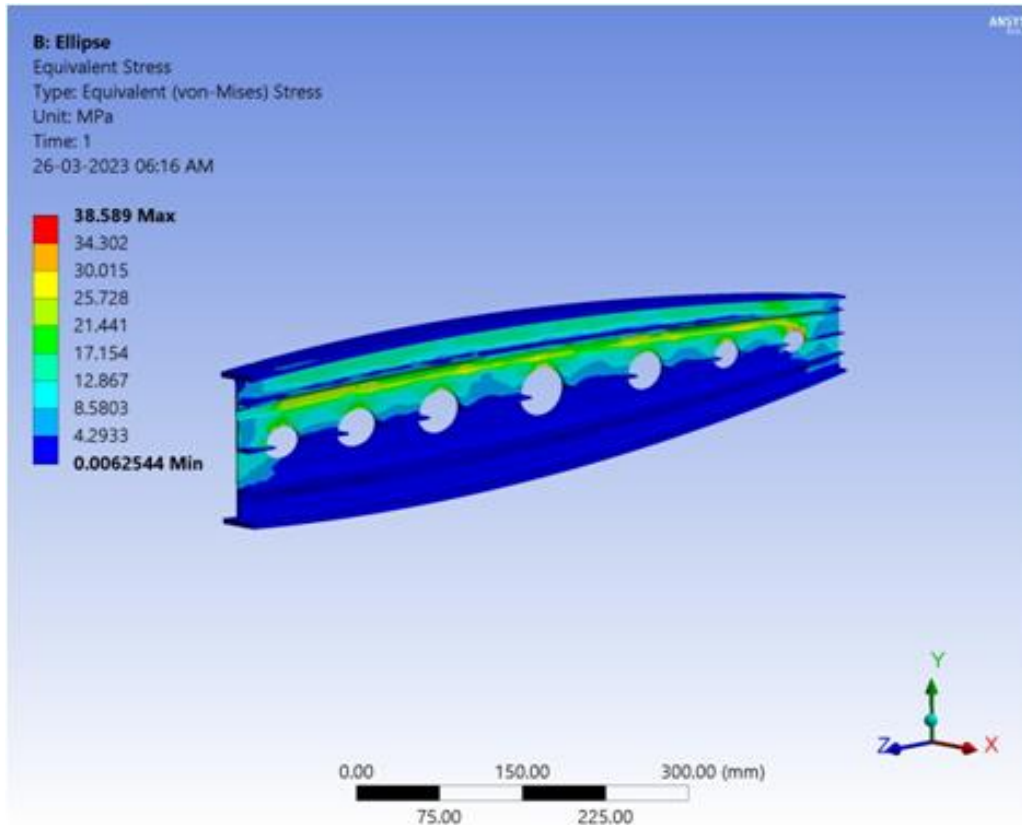


Figure.4.8 Stress for Elliptical Cut-out

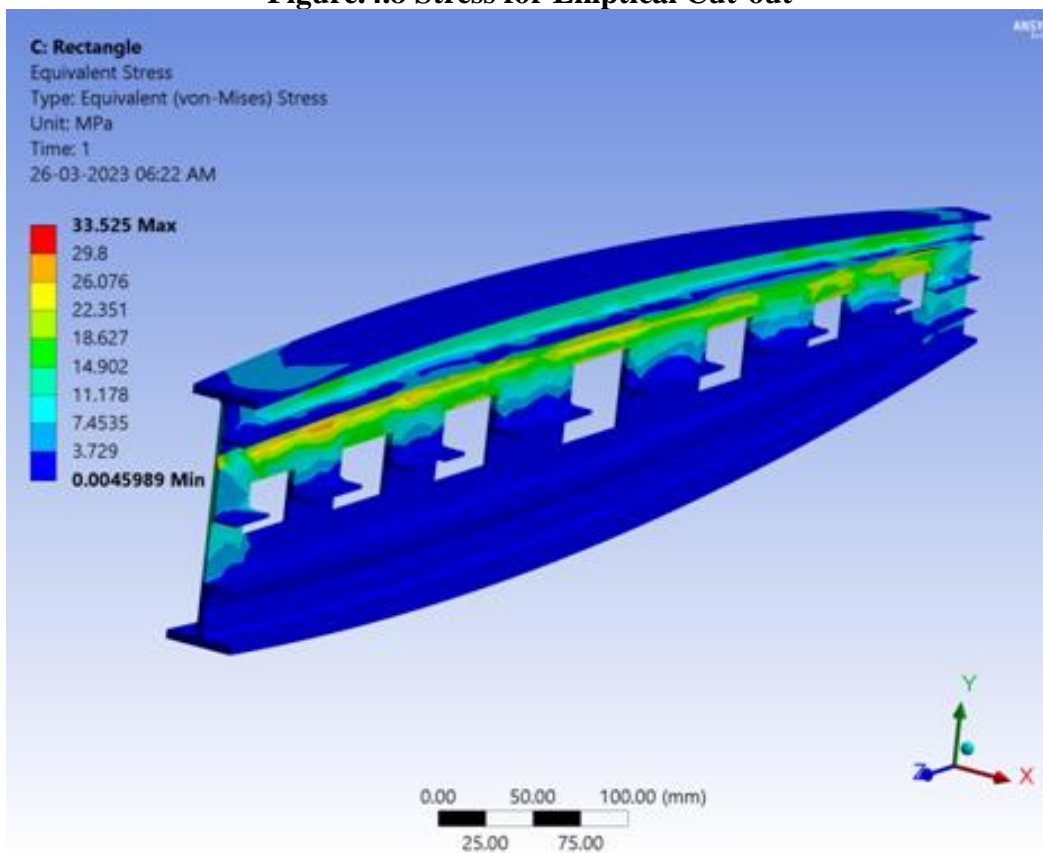


Figure.4.9 Stress for Rectangular Cut-out

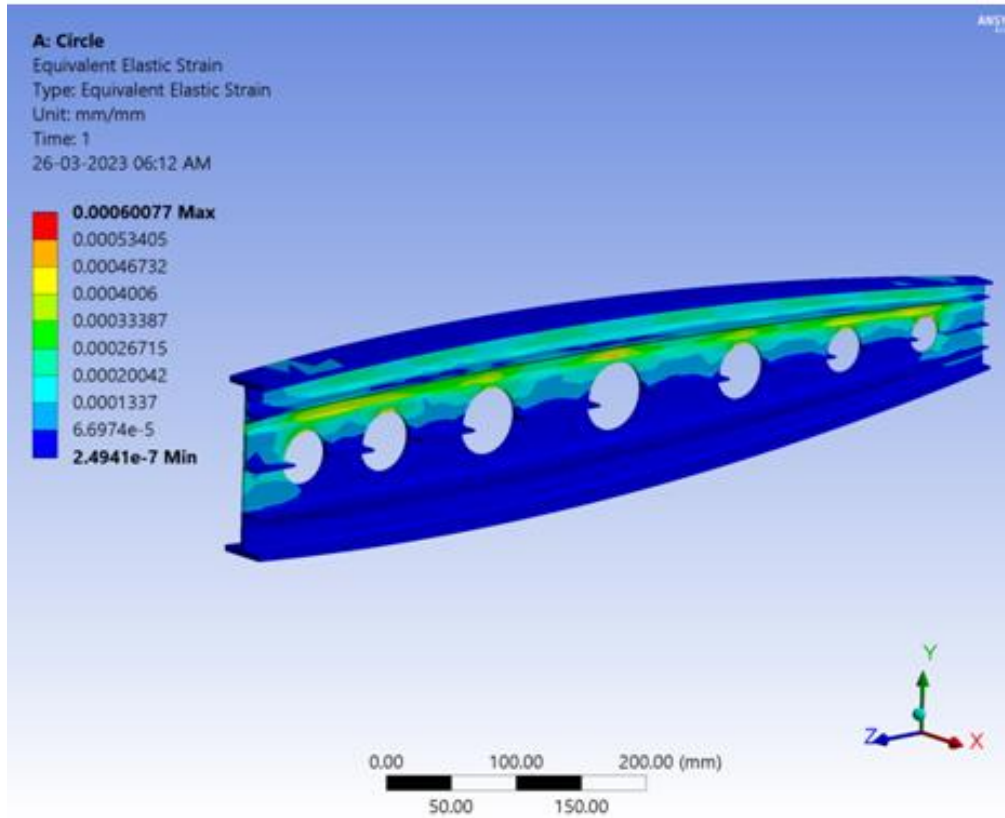


Figure.4.10 Strain for Circular Cut-out

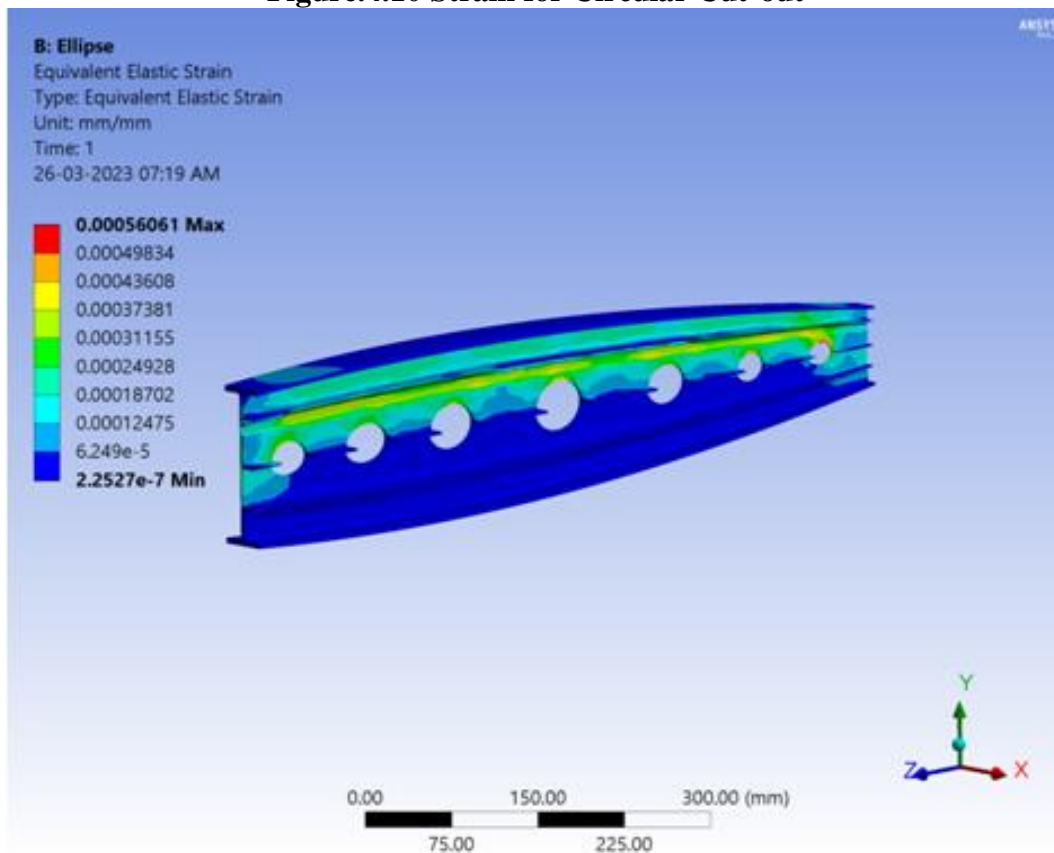


Figure.4.11 Strain for Elliptical Cut-out

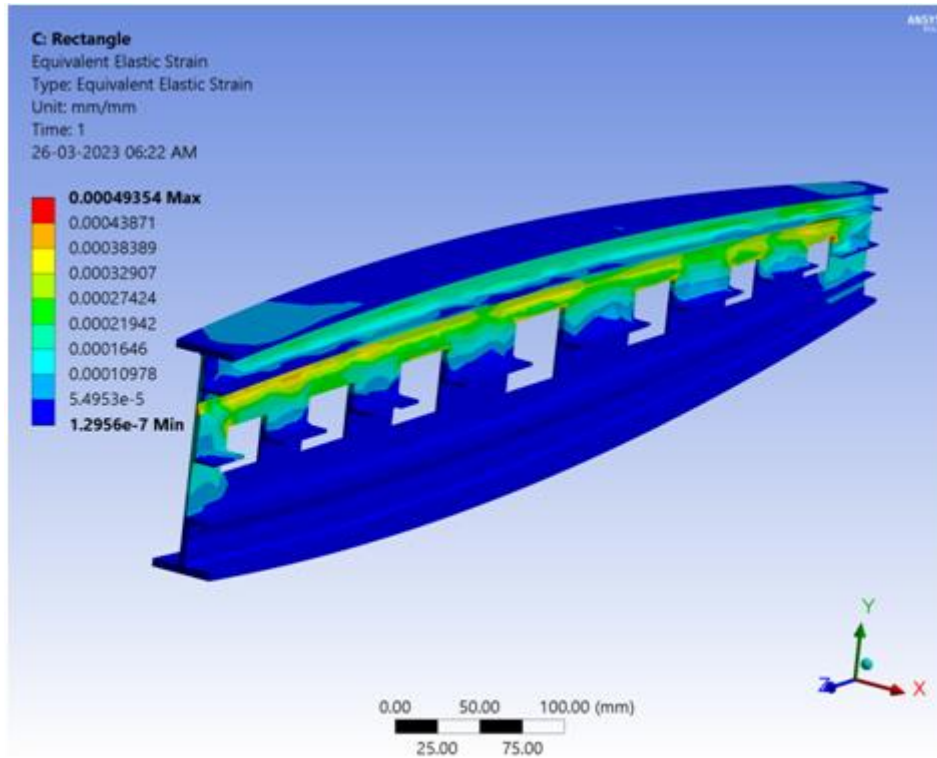


Figure.4.12 Strain for Rectangular Cut-out

5. RESULT & DISCUSSION

Table.5.1 Structural Behavior

| Model | Deformation(mm) | Stress (MPa) | | Strain | | Weight (Kg) |
|------------|-----------------|--------------|-------|-----------------------|---------|-------------|
| | Max | Min | Max | Min | Max | |
| Circle | 0.038 | 0.0057 | 42.18 | 2.49×10^{-7} | 0.00060 | 1.65 |
| Elliptical | 0.036 | 0.0062 | 38.59 | 2.25×10^{-7} | 0.00056 | 1.67 |
| Rectangle | 0.04 | 0.0045 | 33.53 | 1.29×10^{-7} | 0.00049 | 1.66 |

The diagrams shown are the structural behavior of rib section while it's subjected to the loads acting over the rib section. In terms of all parameters the model without any cutout will have higher performance. But in aircraft the rib section has to be made with cutouts, where the cutout has to be made for fuel piping and to add some other structural members for the wing. So the main concentration in here is for the rib section with cutouts. The deformation of the rib with elliptical cutout section has a very less deformation when compared to other models. But in terms of other parameters like stress, strain and weight the rectangular cutout has a better performance. The stress acting over the circular model is of 0.0057 MPa to be a minimum and the maximum stress is of 42.18 MPa, where for elliptical mode the minimum stress is of 0.0062 MPa and maximum is of 38.59 MPa and for the triangular mode minimum stress is of 0.0045 MPa and maximum is of 33.53 MPa.

6.CONCLUSION

So from this it's clear that the triangular cutout model holds a higher stress over the model. Also in terms of weight the circular cutout model is of 1.65 Kg, for elliptical model with 1.67 Kg and rectangular model of 1.66 Kg. So as a result the model with rectangular cutout has a better performance so as this could be implemented for the rib sections.

REFERENCES

- [1]. Grigory I. Nesterenko, “Service life of airplane structures”, Central Aerohydrodynamic Institute (TsAGI), Russia, 2002.
- [2]. A Rama Chandra Murthy, G S PalaniNagesh R Iyer, “Damage tolerant evaluation of cracked stiffened panels under fatigue loading”, *Sadhana* Vol. 37, Part 1, February 2012, pp. 171–186.
- [3]. AdarshAdeppa, Patil M S and Girish K E (2012), “Stress Analysis and Fatigue Life Prediction for Splice Joint in an Aircraft Fuselage through an FEM Approach”, *International Journal of Engineering and Innovative Technology (IJEIT)*, Vol. 1, No. 4, pp. 142-144.
- [4]. J. C. Newman, Jr, “Advances in fatigue and fracture mechanics analyses for aircraft structures”, *Mechanics and Durability* Branch, NASA Langley Research Center, Hampton, VA, USA.
- [5]. A. Brot et al., “The damage-tolerance behaviour of integrally stiffened metallic structures”, *Israel Annual Conference on Aerospace Sciences*, 2008
- [6]. F.H.Darwish, G.M.AtmeH, Z. F. Hasan Design (2012) “Analysis and Modelling of a General Aviation Aircraft” Volume 6, Number 2, ISSN 1995-6665 Pages183 – 191.
- [7]. Michael Chung Yung Niu, “Airframe Structural Design”, *Comilit press Ltd*, 1989, pp. 90-117 .MichaelBauccio (1993), *ASM Metals Reference Book*, 3rdEdition, ASM International, Materials Park, OH.
- [8]. Fawaz, S. A. and BörjeAndersson. “Accurate Stress Intensity Factor Solutions for Unsymmetric Corner Cracks at a Hole”. *Proc. of the Fourth Joint NASA Conference on Aging Aircraft*, vol 15 (2000),pp 135-139
- [9]. C.S. Kusko, J.N. Dupont, A.R. Marder, “Influence of stress ratio on fatigue crack propagation behavior of stainless steel welds”. *Wlding Journal*, vol19,(2004), pp 122-130
- [10]. N. Ranganathan, H. Aldroe, F. Lacroix, F. Chalon, R. Leroy, A. Tougui. “Fatigue crack initiation at a notch”. *InternationalJournal of Fatigue*, vol 33, (2011), pp 492-499